CONDITION-BASED MAINTENANCE PLUS SELECT PROGRAM SURVEY

REPORT LG301T6

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CBM+ Select Program Survey

The objective of this task was to identify a baseline and create a common framework that would facilitate continued expansion of the Condition-Based Maintenance Plus (CBM+) initiative among DoD policy executives, military service leaders, weapon system and maintenance program managers, research activities, and commercial vendors. We established the baseline by surveying select DoD programs within the services to identify the CBM+ technologies and tools of most interest to the program managers, and participating in limited discussions with commercial firms.

We researched 11 examples of current CBM+ programs (in use or under development), the challenges experienced by these programs, and the results being achieved. We grouped the 11 select programs into 3 categories: future programs, fielded programs, and other or multiple-platform applications. We discovered a broad range of general CBM+ characteristics is being addressed within each category, which indicates an existing level of activity (although not a consistently robust level and without supporting metrics). Certain platforms are pursuing a set of CBM+ elements, while others are focused on a single, specific application. Several general maintenance themes emerged as universal considerations for the programs interviewed; among them are cost, diagnostics, and wireless capabilities.

This report presents LMI's recommendations:

- Strengthen policy for the CBM+ initiative at the DoD and service levels.
- Focus on specific CBM+ core issues to achieve quantifiable success and support follow-on applications.
- Establish a framework for executing CBM+ pilots.
- Develop active relationships with commercial and academic activities to refresh and sustain the CBM+ initiative.

BACKGROUND

The requirement for a survey was established in the original CBM+ initiative charter:

> [To] capture and sustain information on the state-of-the-art for maintenance technologies and practices with the stated intentions to share CBM+ related knowledge, to leverage CBM+ improvement efforts among multiple parties and to, ultimately, increase the effectiveness of maintenance capabilities across DoD.

The CBM+ initiative is dynamic, evolving over time as new technology and practices are developed and fielded. The survey is intended to be reviewed and updated, as appropriate, to capture progress in specific military and commercial efforts. Updates will also document new developments of interest to the CBM+ Advisory Group, their sponsor, the Maintenance Senior Steering Group (MSSG), and the wider audience of CBM+ proponents, engineers, logisticians, and program management personnel interested in improving their weapon system's performance through maintenance practices and procedures.

THE CBM+ INITIATIVE

The CBM+ initiative encompasses a wide variety of technologies, tools, processes and procedures as they apply to the maintenance of DoD weapon systems. The intent of the CBM+ initiative is to identify, encourage, and coordinate military service plans to increase operational availability and materiel readiness throughout the weapon system life cycle at a reduced cost. By employing a dynamic weapon system maintenance strategy while providing maintainers with accurate information and effective maintenance tools, improved materiel availability for the warfighter will be achieved. Application of CBM+ will enhance visibility of the real-time status of mission equipment, minimize maintenance footprints, enable the integration of multiple logistics systems, and more effectively utilize limited maintenance resources in the support of combat capability.

CBM+ DEFINED

Condition-based maintenance (CBM) is an established and accepted maintenance practice that derives maintenance requirements, in large part, from real-time assessment of weapon system condition obtained from embedded sensors and/or external tests and measurements using built-in or portable diagnostic equipment. The goal of CBM is to perform maintenance based only upon the evidence of a need rather than any predetermined time cycle, equipment activity count, or other engineered basis.

CBM+ builds squarely on the foundation of CBM and is focused on inserting state-of-the-art maintenance applications, technologies, and techniques to improve the maintainability and availability of both new and legacy weapon systems. It involves business processes reengineering to dramatically improve logistics system responsiveness. Capabilities within the CBM+ initiative include enhanced prognosis and diagnosis techniques, failure trend analysis and electronic portable maintenance aids, automatic identification technology and data-driven interactive maintenance training—a broad range of tools that serve to enhance the maintainer's ability to support equipment and weapon systems effectively and efficiently.

The following characteristics are among those associated with CBM+:

- *Hardware*—embedded sensors, built-in-test, built-in-test-equipment, and integrated data bus
- *Software*—decision support and analysis capabilities, diagnostics, prognostics algorithms, and health management
- *Communications*—databases and off-board interactive communications links
- *Design*—open system architecture, integration of maintenance and logistics information systems, and an interface with operational systems
- *Processes*—reliability-centered maintenance (RCM); a balance of reactive, preventive, and predictive maintenance actions; and CBM
- *Tools*—interactive electronic technical manuals (IETMs), automated identification technology, and portable maintenance aids
- *Functionality*—fault detection, isolation, prediction, reporting, assessment, and recovery.

DoD Select Programs/Concepts

In January 2004, the military services were asked to nominate programs or platforms to serve as lead programs for CBM+ research and to participate in this initial CBM+ stakeholders' survey (memorandum provided in Appendix A). The selection criteria isolated programs that were distinguished by their active approach to and activity with the CBM+ technologies, processes, and procedures.

The resulting mixture included fielded and future programs, a system development office, and a number of broad maintenance initiatives that are not platform unique (designation memorandum provided in Appendix B). The programs in the select category, which may change over time at the request of the Advisory Group's members, are available for continued analysis to help expand the overall CBM+ scope and knowledge base. The following select programs exhibit activity in a variety of CBM+ efforts.

- Army
  - *Future Combat Systems/Unit of Action (FCS/UA*) is a suite of 18 manned and robotic air and ground vehicles. Systems are planned to be introduced incrementally between 2008 and 2014.
  - The *Stryker* program comprises a family of more than 2,000, 19-ton wheeled armored vehicles in 10 configurations and is being fielded. Most of the Stryker CBM+ elements are still being developed.

- *AH-64 Apache* involves a fleet of more than 700 A- and D-model attack helicopters that have been in service up to 20 years. An A-to-D upgrade program is in progress.

- Navy
  - *Maintenance Effective Review (MER)* incorporates a Naval Sea System Command–developed continuous process that applies reliability-centered maintenance to current maintenance practices and validates ship maintenance requirements.
  - *Engineering for Reduced Maintenance (ERM)* comprises a family of initiatives (including labor-saving technologies, tools, paints, and diagnostics and prognostics) that are used to extend maintenance periods or eliminate a maintenance requirement.
  - *Integrated Condition Assessment System (ICAS)* is an online automated machinery condition monitoring and assessment program currently installed on ships across 12 classes.
- Air Force
  - *C-17 Globemaster III* is a fleet of 120 strategic transport aircraft (still in production; 180 are planned).
  - The *Joint Strike Fighter (JSF)* program involves a family of more than 2,000 strike fighter aircraft for the Navy, Air Force, Marine Corps, and U.S. allies, with three variants planned for an initial fielding in 2010.
  - *Service Parts Ordering Tool (SPOT)* is a Defense Logistics Agency logistics research and development initiative that added an electronic parts-ordering capability to the IETMs for the Air Force E-3 Sentry airborne early warning aircraft.
- Marine Corps
  - *Expeditionary Fighting Vehicle (EFV)*, formerly the Advanced Amphibious Assault Vehicle, is a fleet of more than 1,000 tracked vehicles, with two variants planned for initial fielding in 2008.
  - *Light Armored Vehicle (LAV)* is a fleet of more than 700, 11–14-ton wheeled vehicles in eight configurations. A service life-extension program is in progress.

CBM^+ is not limited to these programs, but study of these select programs gives us the opportunity to more closely scrutinize the CBM^+ processes and gauge progress and effectiveness. The occasion and feasibility to apply or insert CBM^+ technologies and processes varies with the maturity and complexity of the weapon systems and platforms, the resources available to accomplish individual initiatives, and the operational performance experienced in the field.

Although consistent objectives can exist or similar technologies may be shared, we did not anticipate—nor did we discover—any standard CBM$^+$ package. This is due to a number of mitigating factors, including

- manufacturer proprietary issues;
- acquisition status;
- program manager prerogatives, priorities, and funding;
- operational tempo and schedules;
- unique equipment configuration; and
- equipment age.

THE CBM$^+$ STAKEHOLDERS' SURVEY

LMI developed and distributed a survey questionnaire (provided in Appendix C) to collect information from select programs in various stages of maturity (from design and development to fielded, non-platform-specific applications) and commercial activities. Using the survey, we attempted to identify different CBM$^+$ elements within the programs, including CBM$^+$-related technologies, processes, and procedures; anticipated or actual costs and benefits of the specific initiative or the effect of CBM$^+$ on the entire weapon system; program goals and the metrics used to gauge their progress; and any available supporting analysis.

FINDINGS

The survey addressed programs across the life-cycle timeline of weapon systems, from the early design and development phases to fielded assets (program life-cycle distribution provided in Appendix D). Because some of the select programs are broad process-improvement initiatives (versus a weapon system program office), or possibly because of their multiple platform applications, not all programs fit a standard timeline. For that reason, we created three general categories:

- Future platforms
- Fielded platforms
- Other or multiple-platform applications.

These categories allowed us to display CBM$^+$ characteristics and attributes among broader sets, and assisted in the identification of general CBM$^+$ trends rather than specific program activity.

Future Platforms

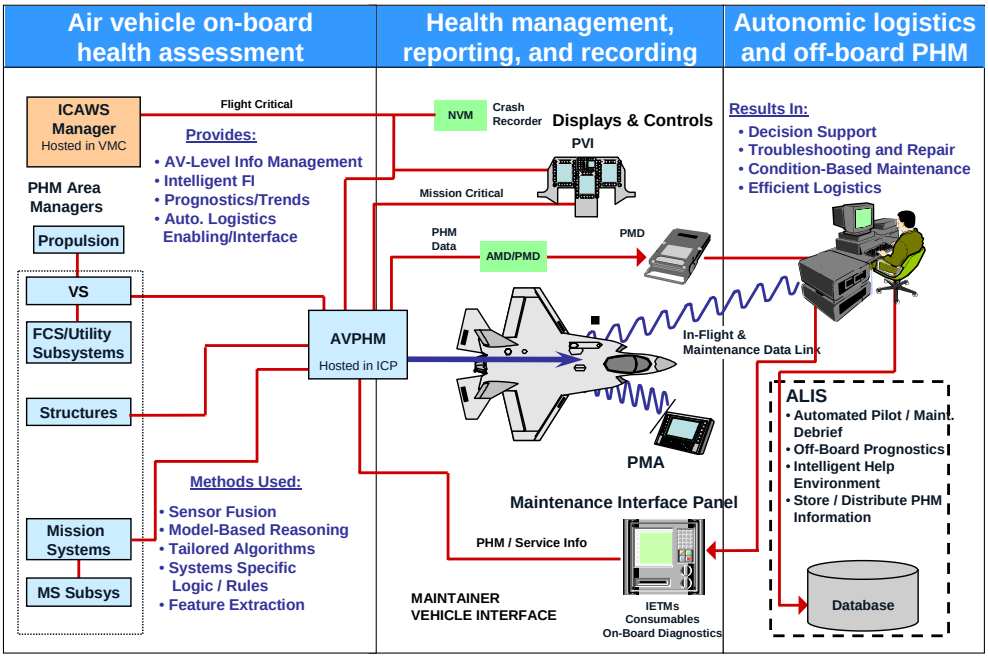
In general, future platforms explore both available and emerging diagnostic and prognostic sensor technologies for mechanical and electronic systems. Integrated information systems and digitized maintenance environments will likely be their end state. See Appendix E for further details.

The following salient findings surfaced during the future platforms surveys:

- The programs' operational requirement documents (ORDs) (now, the capability development documents or CDD) have been used to identify their key CBM$^+$ performance parameters.
- As expected with major acquisition programs, cost, maintainability, and readiness are important factors in CBM$^+$ technology selection and have motivated a high level of detail and rigor on the selection process.
- "Color of money" and timeliness of funding are the most relevant obstacles to CBM$^+$ implementation, followed by technology maturity issues.
- According to survey responses a robust wireless communication capability and improved mechanical or electronic prognostics is the most eagerly anticipated CBM$^+$ technologies for future platforms.

Figure 1 presents an example of a future platform's broad vision from the JSF program.

Figure 1. Future Platform's Broad Vision from the JSF Program (PHM Architecture and Enabling Technologies)



Fielded Platforms

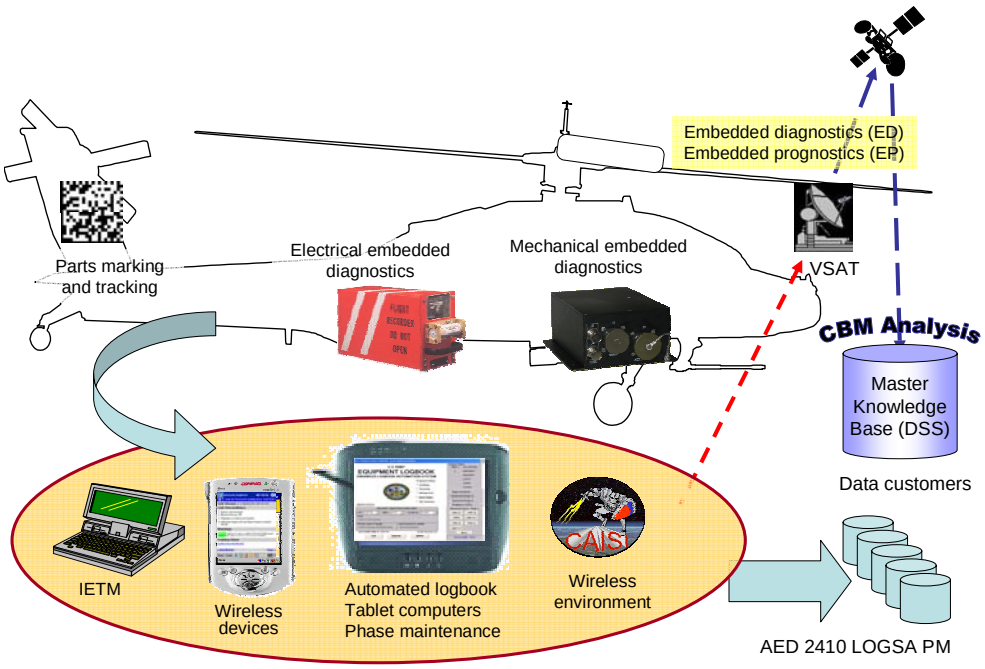
In general, fielded platforms integrate existing or proven technologies into their weapon systems to maintain or improve readiness as a response to fleet operational concerns and weapon system availability experience. Exploration and application of advanced CBM$^+$ technology is also considered for some future long-term modifications. See Appendix F for further details.

The following salient findings surfaced from the fielded platform surveys:

- Select fielded programs use already funded and approved service policies and programs to enable their CBM$^+$-related efforts (i.e., recapitalization, performance-based logistics, Common Logistics Operating Environment).
- Cost, maintainability, and readiness are important factors in CBM$^+$ technology selection for fielded platforms.
- Legacy information technology processes and the compatibility of new CBM$^+$ technologies with existing fielded systems are relevant obstacles to successful CBM$^+$ implementation.
- Wireless and improved electronic prognostics are among the CBM$^+$ technologies that need significant advancement before they can be readily adopted.

Figure 2 illustrates an example of a fielded platform's approach from the Apache program maintenance automation initiatives.

Figure 2. Fielded Platform's Approach from the Apache Program



OTHER AND MULTIPLE-PLATFORM APPLICATIONS

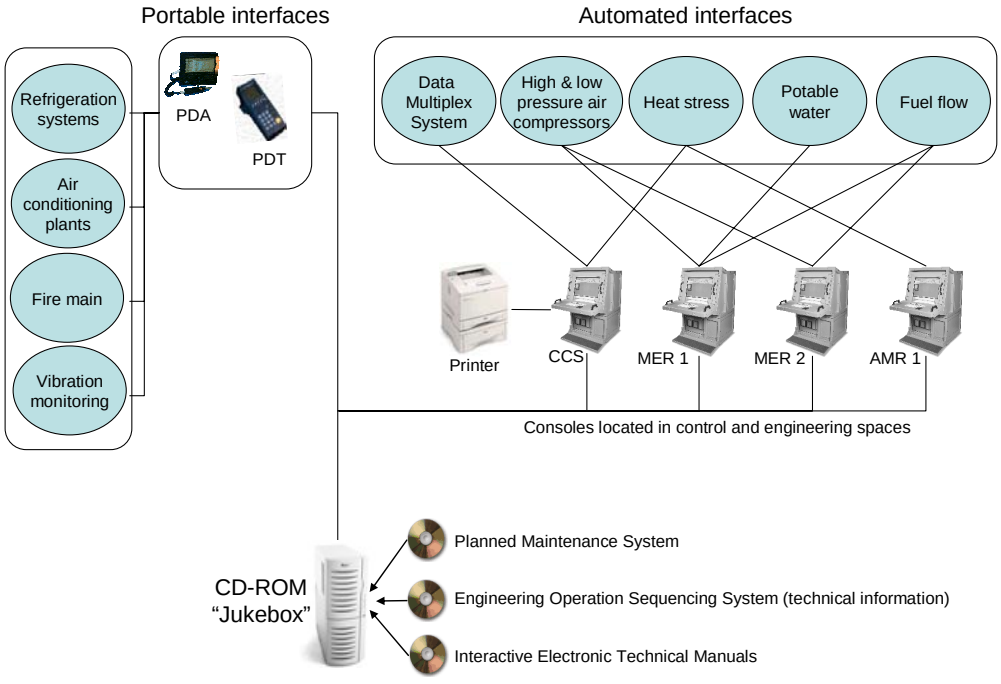
Programs and processes in this category vary in application and purpose from specific support aspects (SPOT) to maintenance procedures across a whole fleet (ERM). See Appendix G for further details.

The following salient findings surfaced during the other and multiple-platform applications surveys:

- These programs use a variety of guidance to enable them to pursue CBM$^+$ initiatives (e.g., DoD and service RCM instructions, specific commodity guidance, military service CBM regulations, and ORD specifications).
- Cost and manpower efficiency were the primary selection criteria for CBM$^+$ project selection.
- Program funding reductions and out-year funding were the primary obstacles to future implementation.
- Wireless and better corrosion sensors are among the CBM$^+$ technologies that need significant advancement before they can be readily adopted.

Figure 3 illustrates a multiple-platform application from the ICAS program.

Figure 3. Current Shipboard ICAS Installation



Note: ICAS can monitor and analyze 65 different ship-installed hull, mechanical, and electric systems through manual or automatic collection of parametric and vibration data.

OTHER CBM+ EXPERIENCE AND COMMERCIAL ACTIVITY

We also gathered preliminary information from the commercial sector to sample CBM+-related activity that might be relevant to DoD. Industry is the initial development source for many of the CBM+ solutions inserted into new and fielded equipment and the integrator or manager of maintenance and logistics efforts through agreements such as performance based logistics. Industry also can be the source of maintenance performed on the platform. As an acquisition or development source for the original weapon system, the commercial sector often provides the framework for critical CBM+ attributes that affect the platform across its entire life cycle. Both original equipment manufacturers and a growing number of solution-specific vendors are actively developing and advancing CBM+ technologies, tools, and processes for both future and fielded platforms. As CBM+ guidance and goals are established, program managers will become smarter buyers of improved maintenance features and capabilities.

The information we gathered from the limited commercial activity interviews was incomplete and is not included in the findings or conclusions of this survey. However, there is potential in this segment of CBM+ activity, and we recommend its analysis in future efforts.

CONCLUSIONS

With the findings and observations summarized in our survey, we were able to conclude the following:

- When grouped in the three general categories, the CBM+ plans and interests for the select programs capture the entire range of CBM+ characteristics. Because these maintenance strategies pre-date the formal CBM+ initiative, this illustrates that maintenance transformation and modernization activities have always been part of the military services' plans and programs. By leveraging the various efforts of the services, the CBM+ initiative ensures each service can coordinate similar efforts, better focus scarce resources toward the most beneficial projects, and make possible more rapid and further development of innovative maintenance technologies and procedures.

  We present the general characteristics of the select program CBM+ initiatives in Table 1. The table is a snapshot based on our limited survey; it does not reflect previous efforts or new CBM+ activity that may be underway by the select programs.

Table 1. CBM+ Characteristics Impacted by Select Programs

	Future			Fielded			Other				
Characteristics	JSF	Stryker	EFV	APACHE	C17	LAV	ERM	MER	SPOT	UA	ICAS
Hardware	X	X	X	X	X	X	X				X
Software	X	X	X	X	X	X			X		X
Communications	X		X	X			X		X	X	X
Design	X		X	X		X			X	X	X
Processes	X		X	X	X			X		X	X
Tools	X	X	X	X	X	X	X		X	X	X
Functionality	X	X	X	X	X		X				X

- A number of general topics related to CBM+ were repeated in multiple (but not all) programs. The following topics share that common thread (listed in order of priority):
  - *Cost challenges*. All survey respondents expressed some frustration with their ability to estimate, justify, and execute a budget in support of CBM+ incorporation for both new and fielded equipment.
  - *Diagnostics*. The most often-cited feature was the capability to sense and convert materiel condition data into maintenance actions using algorithms and software programs. Most respondents considered diagnostics to be the core capability for CBM and a real challenge.
  - *Readiness reporting*. According to survey statements, full or partial mission capability reporting is a primary measure of unit, activity, and weapon system performance, and is used to gain program support and resources.
  - *IETMs*. Using digital data, technical references with a user-friendly, searchable format enable more responsive and accurate maintenance. Those surveyed also cited advanced training features as an enhancement.
  - *Sensors*. Many respondents identified their need to develop and place monitors at the correct equipment location to identify corrosion, stress, usage, and other factors that are important for condition analysis.
  - *Wireless*. Respondents from the programs expressed a desire to transmit and receive information without being tethered to hardwire connections; thus allowing for maintainer mobility and a faster communication environment.

- More details from the survey responses are in Appendixes E, F, and G, but the survey questions can be broadly summarized as follows:
  - The select programs are eager to adopt CBM+ technologies, but initiatives are challenged to demonstrate affordability, quantifiable results, or a return on investment.
  - Current DoD and military service guidance does not inhibit CBM+ efforts. It appears advantageous to craft future CBM+-related guidance as a clear requirement and to act as an enabler.
  - Cost and benefits are conceptually considered, but specific analyses generally are not available or verified quantitatively.
  - Equipment readiness and maintenance performance are the key metrics for CBM+.
  - Implementation profiles vary widely according to the equipment fleet size and the phase of development or life cycle.
  - Few CBM+ opportunities are rejected or not considered at the program level.
  - The cost and specific funding ("color of money") for CBM+—as well as the established support systems, procedures, and infrastructure—provide a natural resistance to change.
  - Shared experiences are useful in selecting CBM+-related initiatives.
  - All programs have a CBM+ "wish-list." These lists were compiled through no lack of imagination, but generally lack consistent funding.

RECOMMENDATIONS

We recommend the MSSG take the following actions:

- Strengthen CBM+ policy and guidance, either as a stand-alone document or inserted into other references, to
  - establish CBM+ as an unambiguous requirement to improve support for investments and efforts and
  - enable the military services to expand their guidance in support of CBM+ plans and strategy.

- Select CBM+ core issues that exhibit the most significant benefit and system- or service-wide application (e.g., wireless, improved electronic and mechanical sensors, and prognostics for electronics) to
  - identify key maintenance transformation opportunities,
  - coordinate the military services' participation in CBM+ projects, and
  - focus activity to successfully create synergy for additional CBM+ initiatives.
- Establish an execution framework for CBM+ pilot programs that uses funding from multiple appropriation accounts and other available sources to support program-level participation in CBM+ initiatives. Such a framework
  - identifies existing resources to support funding of projects with wide application and potential,
  - encourages service-level participation in CBM+ implementations, and
  - allows access to R&D funding and other resources not readily available at the program level.
- Develop active relationships with non-DoD sources of CBM+ technologies and practices (including commercial vendors and academic research facilities) to
  - refresh the dynamic CBM+ knowledge base that serves as a resource for general education and
  - discover opportunities for teaming, thus providing mutual benefits to all parties.

APPENDIX A. CBM+ SELECT PROGRAMS MEMORANDUM—REQUEST

OFFICE OF THE UNDER SECRETARY OF DEFENSE
3000 DEFENSE PENTAGON
WASHINGTON, DC 20301-3000

ACQUISITION,
TECHNOLOGY
AND LOGISTICS

JAN 06 2004

MEMORANDUM FOR: SEE DISTRIBUTION

SUBJECT: Condition-Based Maintenance Plus (CBM+) Select Programs

Progress for the Condition-based Maintenance Plus (CBM+) initiative is being monitored by the CBM+ Advisory Group. A short outline of each Service's strategic plan for CBM+ is due at the end of this month. To support and focus on-going CBM+ analysis and development, I am requesting the Services nominate two programs each to serve as their lead programs for CBM+. The purpose of the designation is not to narrow CBM+ efforts, but to offer the opportunity for a more detailed assessment of the CBM+ challenges and successes experienced within a consistent set of programs.

For selection, I feel it is critical to choose platforms that you would describe as "leaning forward" to actively embrace CBM+ technologies, techniques, and processes to better define the CBM+ adoption process for the benefit of all DoD. By identifying the pitfalls and risks as well as the benefits, we will be better able to assist other programs more effectively and efficiently implement CBM+. Since CBM+ policy applies to both new and fielded platforms, a mixture of both would be ideal. Platforms in the design and development phase will have different CBM+ challenges than those in the sustainment and modernization mode, and both have important lessons to learn.

No inordinate reporting or resource requirements are anticipated for the select programs, but an open exchange of information and access to platform logisticians, engineers, and operators by the Advisory Group should be expected. Please identify your programs and provide their contact information to COL Sarah Smith, USAF at 703-695-0338 or Sarah.Smith@osd.mil. Our target date for designation is 30 January 2004. I will provide introductory guidance and additional information by separate correspondence directly to the CBM+ select programs with a copy to you.

Please contact me directly with any questions or comments. I look forward to your support for this initiative.

Sincerely,

Robert T. Mason

Robert T. Mason
Assistant Deputy Under Secretary
of Defense (Maintenance Policy,
Programs and Resources)

APPENDIX B. CBM+ SELECT PROGRAMS MEMORANDUM—DESIGNATION

OFFICE OF THE UNDER SECRETARY OF DEFENSE

3000 DEFENSE PENTAGON
WASHINGTON, DC 20301-3000

ACQUISITION,
TECHNOLOGY
AND LOGISTICS

March 30, 2004

MEMORANDUM FOR DIRECTOR FOR SUSTAINMENT (DALO-SMZ), G4, US ARMY
DEPUTY DIRECTOR, FLEET READINESS DIVISION (N43B),
US NAVY
DEPUTY DIRECTOR FOR MAINTENANCE (AF/ILM),
US AIR FORCE
ASSISTANT DEPUTY COMMANDANT, INSTALLATIONS &
LOGISTICS DEPARTMENT, US MARINE CORPS

SUBJECT: Condition-Based Maintenance Plus (CBM+) Select Programs

I would like to thank you for your response to my request for Service nominations to support the CBM+ initiative. The programs you have designated will offer the opportunity for a more detailed assessment of CBM+ challenges and successes. The select programs, listed by Service, are:

Army	Future Combat System (FCS) Stryker Apache
Navy	Maintenance Effective Reviews (MER) Engineering for Reduced Maintenance (ERM) Integrated Condition Assessment System (ICAS) DD (X)
Air Force	C-17 JSF Service Parts Ordering Tool (SPOT) for AWACS
Marine Corps	Expeditionary Fighting Vehicle (EVF, formerly AAAV) Light Armored Vehicle (LAV)

CBM+ policy applies to both new and fielded platforms, and this mixture of both is ideal. The CBM+ Advisory Group will prepare and release introductory guidance. They will be conducting an initial survey of CBM+ activity this spring that will assist in CBM+ baseline development. My lead for CBM+ is COL Sarah Smith at (703) 695-0338 or Sarah.Smith@osd.mil. Please contact her directly with any questions or comments.

for Robert T. Mason
Assistant Deputy Under Secretary
of Defense (Maintenance Policy,
Programs and Resources)

APPENDIX C. SURVEY QUESTIONS

1. Please describe your program's approach to the CBM$^+$ initiative and identify any technologies and processes you have targeted to date.
    - Logistics elements. Are single or multiple elements affected?
    - Integration aspects. Required to interface with other information systems?
    - Cost benefit analysis. Is one completed?
    - Goals and expectations. Have they been met?

2. Has guidance from OSD or your Service enabled you to pursue CBM$^+$?
    - Are you required to achieve specific CBM$^+$ capabilities?
    - How is CBM$^+$ guidance disseminated in your program?
    - Has integration with logistics or operational systems dictated certain CBM+ efforts (mandate for IETMs, connectivity, interoperability)?

3. What are the primary selection criteria for your CBM$^+$ projects? Options might include:
    - Return on investment
    - Total ownership cost
    - Strategic decision (program or Service level)
    - Logistics elements impact (supply, transportation, etc)
    - Manpower reduction

4. What metrics do you use to measure the CBM$^+$ effect on your program or platform? Key metrics might include:
    - Weapon system performance or capability
    - Weapon system readiness (MC/FMC)
    - Maintenance efficiency (automatic fault detection, prognostics, logistics footprint, manpower required)
    - Operating and support costs
    - Connectivity with operational or logistics networks
    - Item or system troubleshooting time or repair turn-around-time
    - Operator or maintainer safety

5. How do you determine the implementation period for your program's fielded equipment and processes? How are CBM$^+$ features incorporated in the design phase of your program? How often is your program reviewed for the possible introduction of new CBM$^+$ technologies not previously developed or available during your last review?

6. Please describe any CBM$^+$ approaches or technologies that you have considered and rejected. What decision process do you use? How is it vetted? Examples might be:
    - Contact memory buttons rejected in favor of RFID
    - CBM$^+$ feature operates well in garrison, but is not supportable in a deployed environment
    - Anticipated technology never materialized

7. What obstacles to successful CBM$^+$ development and implementation do you face and how do you accommodate them?
    - Outside influences (warfighter inputs, engineering analysis, higher approval required)
    - Funding (color of money, multiple sources, budget time lag)
    - Actions of others required for your CBM$^+$ success (global networks, establishing standards)
    - COTS versus government specified issues

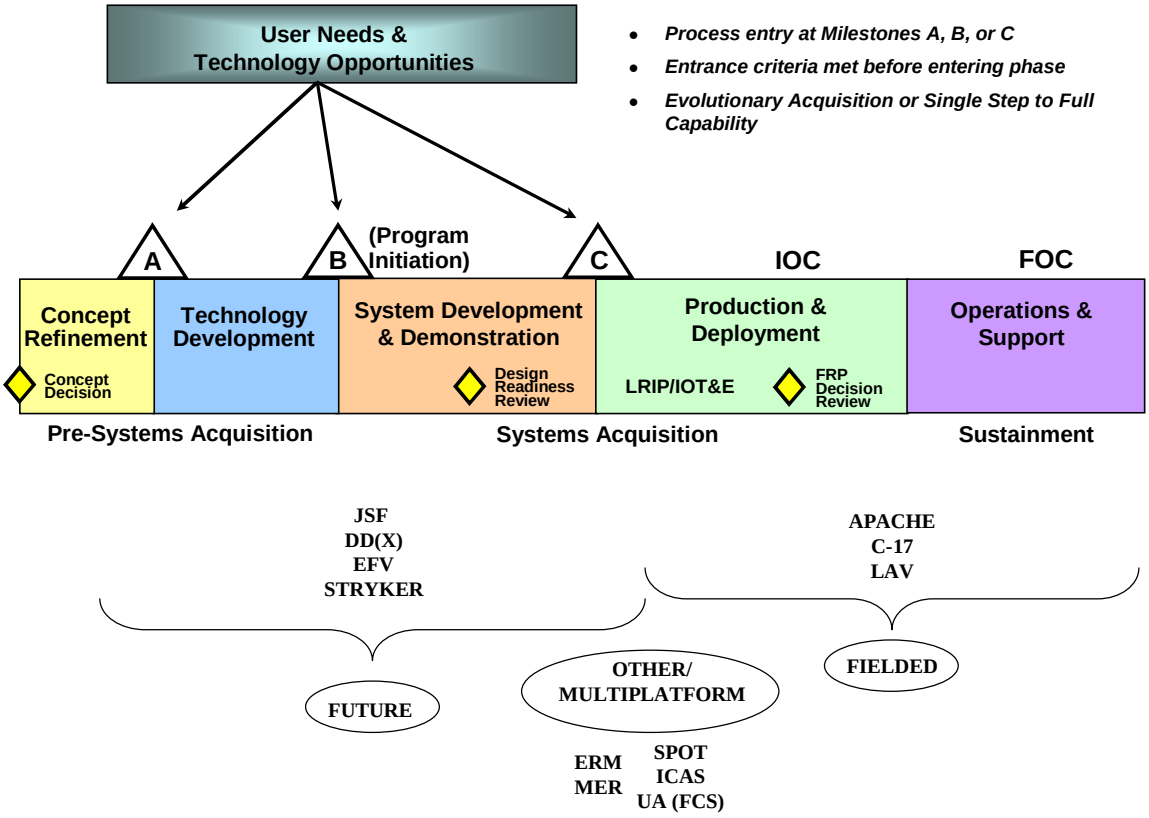
8. Can you identify any technology or process with characteristics similar to CBM$^+$ that has been added to your program through another initiative?
    - Corrosion sensors
    - Engine or component monitoring
    - Fatigue life sensors

9. What new CBM$^+$ technology or process do you desire most for your platform or program? Given the opportunity to add a new maintenance-related feature or application, without regard for cost, what would it be?

APPENDIX D. SELECT PROGRAM LIFE-CYCLE DISTRIBUTION

The generic weapon system life cycle (Figure D-1) illustrates the range of the select programs and reflects the wide window of opportunity for incorporating CBM+ technologies and processes.

Figure D-1. Generic Weapon System Life Cycle



APPENDIX E. SELECT PROGRAM SUMMARY—FUTURE PLATFORMS CATEGORY

Representatives of the Stryker, JSF, and EFV programs responded to the survey the information summarized below.

1. Please describe your program's approach to the CBM$^+$ initiative and identify any technologies and processes you have targeted to date.

Stryker — Phased approach to implementing diagnostics/CBM for:
- High payoff existing technology
- Emerging embedded diagnostics
- Developing predictive maintenance capabilities

JSF — Prognostics and Health Management (PHM) concept uses:
- On-board fault detection/fault isolation (FD/FI) technology
- Predictive technology
- Health management tools

EFV
- ORD dictates CBM requirements
- RCM analysis validates technology

Summary #1: Future programs, being further away from production are looking at the broadest variety of diagnostic and prognostic sensor technologies, for both mechanical and electronic systems.

2. Has guidance from OSD or your Service enabled you to pursue CBM$^+$?

Stryker
- ORD dictates CBM requirements

JSF
- No top level Joint guidance
- PBL and Autolog concept drive program towards CBM$^+$ initiatives

EFV
- HQMC CBM$^+$ guidance dictates program

Summary #2: Acquisition guidance requires CBM$^+$ in ORD. Hard specifications in ORD require manufacturers to implement CBM$^+$.

3. What are the primary selection criteria for your CBM$^+$ projects?

Stryker
- Impact on operator and crew
- Impact of weight and volume
- Mission criticality

JSF Total Operational Cost (TOC)

EFV
- ORD specifications
- Operational acceptability/suitability from “green suiters”
- Life Cycle Cost (LCC) analyses.

Summary #3: Maintainability and cost.

4. What metrics do you use to measure the CBM$^+$ effect on your program or platform?

Stryker Keep readiness rates high by first addressing known or chronic problems and then concentrate on speeding up time to diagnose, remove/replace, and repair

JSF PHM specifies:
- 70% of mechanical systems have FD/FI (fault diagnostics/fault identification)
- 90% of avionics systems have FD/FI

EFV
- MC/FMC rates dictated in ORD
- Maintenance ratio of hours of maintenance to hours of operation
- Percent of vehicle that RCM has been accomplished
- Diagnostic false alarm rate

Summary #4: Readiness (mission capable and maintenance ratios). Fault diagnostics requirements for subsystems are set a high level.

5. How do you determine the implementation period for your program's fielded equipment and processes? How are CBM$^+$ features incorporated in the design phase of your program? How often is your program reviewed for the possible introduction of new CBM$^+$ technologies not previously developed or available during your last review?

Stryker	Engineering development, testing and product development result in a phased approach to fielding
JSF	• Hardware is base lined for standard production • Software will be changed through a spiral approach during production
EFV	• Baseline production program has incremental follow on changes after fielding.

Summary #5: ORD defines the initial production maintenance capabilities. Spiral development for improvement modifications.

6. Please describe any CBM$^+$ approaches or technologies that you have considered and rejected. What decision process do you use? How is it vetted?

Stryker	None, the phased approach with engineering, logistics, safety and funding approvals weed out inappropriate technologies
JSF	None
EFV	• Rejected Built-In-Test-Equipment (BITE) due to excessive weight and space requirements • Uses external test equipment to download diagnostic data

Summary #6: No technology rejected outright. Cost, weight, and space are used in selecting applicable technologies.

7. What obstacles to successful CBM+ development and implementation do you face and how do you accommodate them?

Stryker
- Money and time restrictions
- AIT data collection and analysis processes need better definition.

JSF
- Need better physics of failure models
- Prognostics alert accuracy and timeliness need further development
- Current cost models need to be upgraded.

EFV
- Funding (color of money issues)
- Commercial Off the Shelf (COTS) versus government specified technologies
- Actions of others (networks, standards)
- Outside influences

Summary #7: Money (cost models, timeliness of funding, and color). State of the art (AIT, standards accuracy).

8. Can you identify any technology or process with characteristics similar to CBM+ that has been added to your program through another initiative?

Stryker None

JSF
- Engine is on condition
- Two level maintenance concept
- Extended inspection intervals

EFV None

Summary #8: Willing to take any opportunity to borrow “best of breed” from existing military and commercial programs.

9. What new CBM^{+} technology or process do you desire most for your platform or program? Given the opportunity to add a new maintenance-related feature or application, without regard for cost, what would it be?

Stryker	Improved diagnostics and prognostics capabilities
JSF	• Improved sensors for mechanical subsystems • Better prognostics for electronic subsystems • Upgraded corrosion sensors in cavities/fuel tanks • WIFI self powered, sensitive sensors • Better Operational and Support (O&S) models
EFV	WIFI to download data from the vehicle diagnostic systems

Summary #9: WIFI. Improved diagnostics and prognostics, which includes advanced sensors (corrosion and sensitivity issues). Improved electronic prognostics.

APPENDIX F. SELECT PROGRAM SUMMARY—FIELDED PLATFORMS CATEGORY

Representatives of the C-17, LAV, and Apache programs responded to the survey with the information summarized below.

1. Please describe your program's approach to the CBM$^+$ initiative and identify any technologies and processes you have targeted to date.

C-17	• CBM$^+$ efforts are initiated through their Performance Based Logistics (PBL) requirements process, along with the Material Airframe Improvement Program (MIP) • Health monitoring for the F117 engine • Diagnostic, identification and test systems for components • IETMs
LAV	• Integrated Data Environment (IDE) concept creates CBM$^+$ requirements; • IETMs, Class III to Class V • Platform and subsystem sensors • Upgraded Test Measurement and Diagnostic Equipment (TMDE)
Apache	RECAP drives CBM for predictive maintenance, sensor, diagnostic/prognostics and system integration upgrades

Summary #1: Legacy systems incorporate existing and proven CBM$^+$ technology. Short-term fixes applied to maintain readiness. Exploring long-term (advanced technology) fixes for future modifications.

2. Has guidance from OSD or your Service enabled you to pursue CBM$^+$?

C-17	PBL guidance from Air Staff dictates CBM
LAV	USMC HQ CBM$^+$ policy for reducing TOC
Apache	• RECAP requires 90 percent MC • ORD requires embedded diagnostics and prognostics, safety upgrades, and automated data collection • CLOE policy enables CBM

Summary #2: Current logistic process and initiatives used by fielded systems help drive programs toward CBM$^+$ goals. Fielded platforms need or anticipate further military service CBM$^+$ guidance to support resource allocations for future CBM$^+$ efforts.

3. What are the primary selection criteria for your CBM+ projects?

C-17
- HQAMC drives upgrades based on needs requirements and funding availability
- Needs based on existing faults
- On condition criteria

LAV
- TOC reduction criteria
- Applied CBM+ technology to reduce maintenance levels from five to three

Apache
- Return on Investment (ROI)
- Deployed capability scenarios
- MC/FMC

Summary #3: Maintainability and cost.

4. What metrics do you use to measure the CBM+ effect on your program or platform?

C-17
- MC rate of 80 percent
- LRU effectiveness
- MTBM improvement
- RTOC (support cost reduction)

LAV
- O&S cost reduction
- Readiness

Apache
- MC/FMC
- O&S cost reductions
- Connectivity to logistics IT systems
- MTTR
- Safety issues
- Can technology be used in both deployed and garrison scenarios

Summary #4: Readiness (i.e., MC, MTTR, MTBM, etc.) and cost (i.e., TOC, O&S reductions).

5. How do you determine the implementation period for your program's fielded equipment and processes? How are CBM$^+$ features incorporated in the design phase of your program? How often is your program reviewed for the possible introduction of new CBM$^+$ technologies not previously developed or available during your last review?

C-17	Global Reach Improvement Program (GRIP) monitors block upgrades by individual aircraft
LAV	Three year retrofit program
Apache	Block upgrades after testing/validation

Summary #5: Block upgrades are affected by or dependent upon force employment cycles.

6. Please describe any CBM$^+$ approaches or technologies that you have considered and rejected. What decision process do you use? How is it vetted?

C-17	None
LAV	PDA tested and used for configuration management only
Apache	1D barcodes

Summary #6: Fielded platforms are selective and sensitive to the immediate utility of CBM$^+$ technology based on cost, readiness, and manpower utilization.

7. What obstacles to successful CBM$^+$ development and implementation do you face and how do you accommodate them?

C-17	• Legacy maintenance processes, practices, and tools • Boeing Direct Vendor (DV) supply program subcontracts 65 percent of parts
LAV	Compatibility of CBM$^+$ technology with future GCSS-MC
Apache	• Outside influences • Funding issues • Actions of others (standards and network issues) • COTS versus specified issues

Summary #7: Legacy processes. Compatibility issues with future CBM$^+$ technology.

8. Can you identify any technology or process with characteristics similar to CBM$^+$ that has been added to your program through another initiative?

C-17	Avionics Structural Improvement Program
LAV	Battery health monitoring system
Apache	VMEP/MSPU

Summary #8: Took the opportunity to borrow "best of breed" from all existing military and commercial programs.

9. What new CBM$^+$ technology or process do you desire most for your platform or program? Given the opportunity to add a new maintenance-related feature or application, without regard for cost, what would it be?

C-17	Portable Maintenance Aids (PMAs) integrated with IETMs and existing/legacy Technical Orders (i.e., get rid of paper)
LAV	• WIFI at field and garrison level (USMC policy/security issue) • Enhancements to diagnostics for electronics • GCSS-MC compatibility with CBM$^+$ technology • Upgraded health monitoring systems • Solve IETM reader compatibility issues with Class III and Class V upgrades
Apache	• Onboard electronic diagnostic capability • Onboard/off board WIFI of embedded prognostic data • Upgrade off board analysis of embedded prognostics • Improve validation/verification of prognostic algorithms

Summary #9: WIFI. Improved diagnostics and prognostics, which includes advanced sensors (corrosion and sensitivity issues). Improved electronic prognostics.

APPENDIX G. SELECT PROGRAM SUMMARY—OTHER AND MULTIPLE-PLATFORM APPLICATIONS CATEGORY

Representatives of the ERM, MER, UA, ICAS, and SPOT projects responded to the survey with the information summarized below.

1. Please describe your program's approach to the CBM^+ initiative and identify any technologies and processes you have targeted to date.

ERM	Family of initiatives that provide labor reducing technologies with goal of reducing manpower requirements
MER	Uses RCM to validate maintenance practices, resulting in manpower reduction and fewer parts used
UA	Performance Based Logistics (PBL) analysis drives CBM program initiatives
ICAS	Based on CBM, i.e., sensor technology sending on condition data to central processor
SPOT	CBM^+ technology has enabled auto-electronic ordering of parts directly from the flight line IETMs

Summary #1: Focused initiatives to solve specific problems. Limited in broad impact.

2. Has guidance from OSD or your Service enabled you to pursue CBM^+?

ERM/MER	• SECNAV INST based on OSD CBM guidance • DoDI4151.18 (RCM guidance) • OPNAV 4700.7 (RCM) • OPNAV 4790
UA	Supportability Strategic Control Document dictates CBM^+ development and associated contracts and specifications
ICAS	OPNAV4790 requires CBM, (not CBM^+)
SPOT	The Commodity Management System Consolidation Program generated the requirement

Summary #2: Unique solutions for a variety of problems.

3. What are the primary selection criteria for your CBM^{+} projects?

ERM	• Cost benefit and cost avoidance savings • Fleet input
MER	RCM rules guide selection
UA	• Operational capability (for high and low intensity conflicts) • Mission
ICAS	• TOC • Manpower reduction
SPOT	• Reduction in error rate • Manpower reduction

Summary #3: Cost and manpower efficiency.

4. What metrics do you use to measure the CBM^{+} effect on your program or platform?

ERM	Cost avoidance and manpower reduction savings
MER	Workload reduction performance
UA	• MC/FMC rates outlined in PBL planning • Safety issues
ICAS	Fuel and manpower savings for collection and analysis of data
SPOT	• Error rate • Manpower reduction

Summary #4: Manpower efficiency.

5. How do you determine the implementation period for your program's fielded equipment and processes? How are CBM$^+$ features incorporated in the design phase of your program? How often is your program reviewed for the possible introduction of new CBM$^+$ technologies not previously developed or available during your last review?

ERM	As required (fleet installed, 30%; shipyard/contractor installed, 70%)
MER	Routine revisions sent to fleet
UA	Incremental growth through technology upgrades as prognostics/diagnostics validated
ICAS	Normal retrofit through fleet and shipyards
SPOT	Service release and implementation after final testing and validation

Summary #5: Subject to desires and availability of weapon system program manager.

6. Please describe any CBM$^+$ approaches or technologies that you have considered and rejected. What decision process do you use? How is it vetted?

ERM	• Technologies not cost effective are: - Autolub bearings - Breaker failure predictions - Motor failure measurements • Work environment products not compatible were wearable computers (to bulky)
MER	None
UA	None, New program (paper system)
ICAS	Wireless, not advanced far enough for types machinery within data collection program (WIFI not Navy approved for off shipboard use)
SPOT	None

Summary #6: N/A

7. What obstacles to successful CBM$^+$ development and implementation do you face and how do you accommodate them?

ERM	Safety and mission dictate priority
MER	• Program fund reductions • No CBM$^+$ funds dedicated
UA	Out year funding
ICAS	COTS versus government specified standards and technology
SPOT	None

Summary #7: Cost.

8. Can you identify any technology or process with characteristics similar to CBM$^+$ that has been added to your program through another initiative?

ERM/MER	Maintenance Engineering Technology (MET) group identify/vet all technology improvements prior to being applied or evaluated by ERM/MER project offices
UA	None, paper system
ICAS	None
SPOT	None

Summary #8: N/A

9. What new CBM^{+} technology or process do you desire most for your platform or program? Given the opportunity to add a new maintenance-related feature or application, without regard for cost, what would it be?

ERM	Corrosion sensors and predictive analysis for voids/tanks, etc.
MER	Need technology to address reduction of corrosion
UA	General Future Combat System (FCS) technology development and advancements
ICAS	• Instant WIFI transmission of data on/off ship • Prognostic upgrades for all ship installed equipment
SPOT	• Wireless transmission from planeside to IPB (supply) system • Solve SPOT-CAMS interface problems

Summary #9: Wireless and corrosion sensors.

APPENDIX H. ABBREVIATIONS

CBM	condition-based maintenance
CBM^{+}	Condition-Based Maintenance Plus
EFV	Expeditionary Fighting Vehicle
ERM	engineering for reduced maintenance
ICAS	Integrated Condition Assessment System
IETM	interactive electronic technical manual
JSF	Joint Strike Fighter
LAV	Light Armored Vehicle
MER	maintenance effective reviews
MSSG	Maintenance Senior Steering Group
ORD	operational requirement document
R&D	research and development
RCM	reliability-centered maintenance
SPOT	Service Parts Ordering Tool
UA	unit of action

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14. ABSTRACT

The objective was to identify a baseline and create a common framework that would facilitate continued expansion of the Condition-Based Maintenance Plus (CBM^+) initiative among DoD policy executives, military service leaders, weapon system and maintenance program managers, research activities, and commercial vendors. We established the baseline by surveying 11 select DoD programs within the services to identify the CBM^+ technologies and tools of most interest to the program managers, and participating in limited discussions with commercial firms. We grouped the 11 select programs into 3 categories: future programs, fielded programs, and other or multiple-platform applications. We discovered a broad range of general CBM^+ characteristics is being addressed within each category, indicating an existing level of activity (although not consistently robust and without supporting metrics). Several general maintenance themes emerged as universal considerations for the programs interviewed; among them are cost, diagnostics, and wireless capabilities.

LMI's recommendations are: strengthen policy for the CBM^+ initiative at the DoD and service levels; focus on specific CBM^+ core issues to achieve quantifiable success and support follow-on applications; establish a framework for executing CBM^+ pilots; and develop active relationships with commercial and academic activities to refresh and sustain the CBM^+ initiative.

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